Short Course on Experimental Dynamic Substructuring

Module #10: a. Source Description

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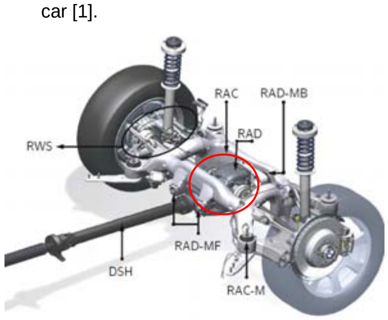
Short Course Notes For:
February 1, 2014, IMAC, Orlando, Florida

Why do we need to source characteristics ?

Frequency Based Substructuring (FBS) allows building a dynamic model of an assembly. This allows predicting eigenfrequencies, modes and damping. But if one is interested in vibration levels one needs to know the source of the excitation.

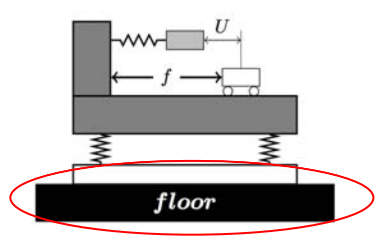
- Example 1:

Excitation generated by bearings and gears within a gearbox in a car. When engineering a car for comfort, it is of great importance to understand how these vibration are transmitted to the rest of the car [1].

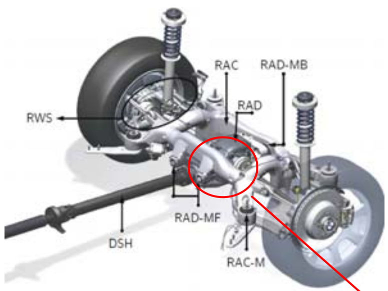


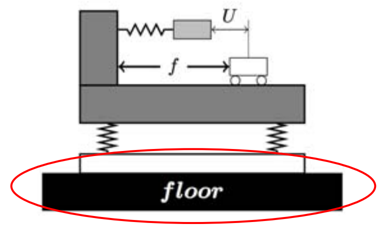
- Example 2:

Vibration of a factory floor on which a high-precision machine needs to be installed. Also in that case predicting the vibration levels transmitted to the machine is essential in order to guarantee its proper functioning [2].



Why do we need to source characteristics ?





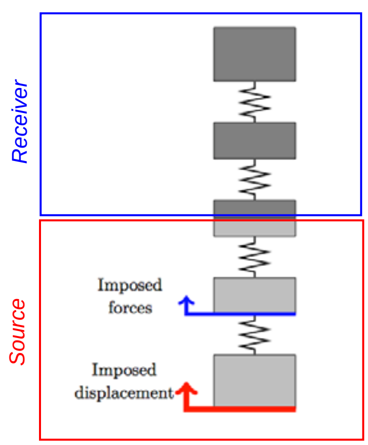
Sources are characterized by

•their own dynamics (FRFs of the source component)
•the description of the excitation as it is seen by the neighbors.

Some source components need to be measured with fixed interface or with free interface

Ingredients of a coupled analysis

Schematic representation of the problem:



Measured or modeled FRF of receiving structure
Y^B

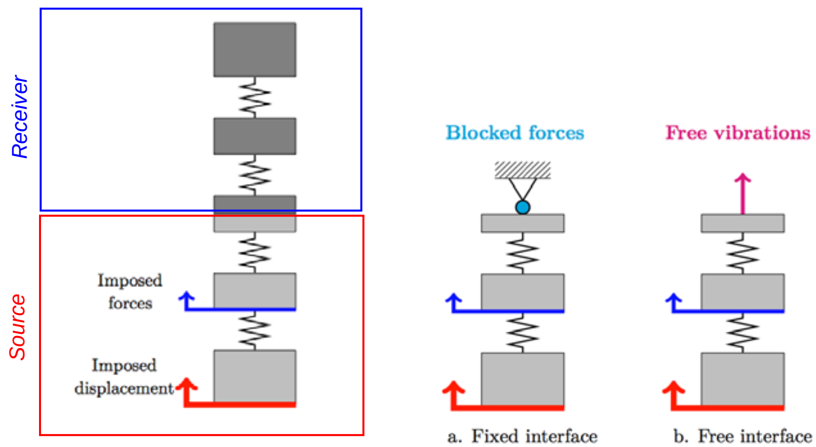
Assembled FRF through FBS

Y^A
Measured or modeled FRF of source structure

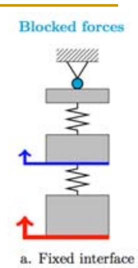
How can we characterize the excitation source if the imposed loads in substructure A cannot be measured ?

Ingredients of a coupled analysis

2 basic options to characterize the source excitation:

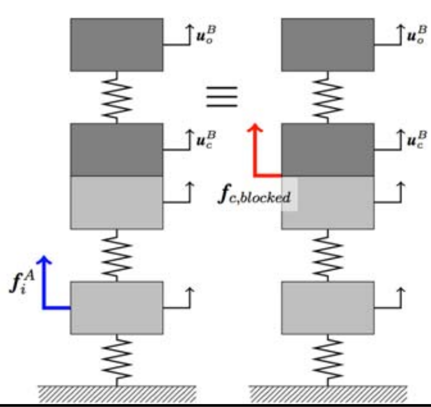


The blocked force approach



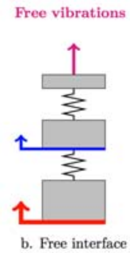
Calling $f^A_{c,blocked}$ the force measured at the ***fixed*** interface of the source, it can be shown (using primal and dual assembly forms) that [2,3] …

<u>For the receiving substructure B</u>, the response is identical if the true source is applied or if the blocked force is applied on the interface as external force on the source+receiver assembly.



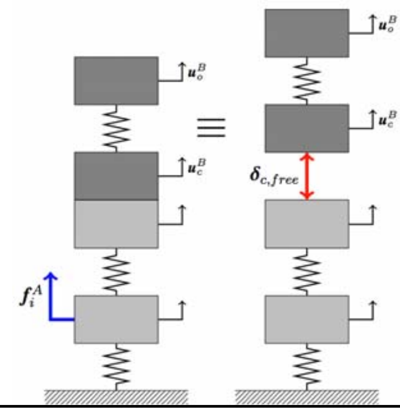
$$\begin{bmatrix} u_i^B \\ u_c^B \end{bmatrix} = - \begin{bmatrix} Y_{ic}^B \\ Y_{cc}^B \end{bmatrix} \left(Y_{cc}^A + Y_{cc}^B\right)^{-1} Y_{cc}^A f^A_{c,blocked}$$

Free interface displacements approach



Calling $\delta_{c,free}^{A}$ the displacement measured at the ***free*** interface of the source, it can be shown (using primal and dual assembly forms) that [2,3] …

***<u>For the receiving substructure B</u>*, the response is identical if the true source is applied or if the free interface displacement is imposed as** *relative* **displacement between the source and the receiver.**



$$\begin{bmatrix} u_i^B \\ u_c^B \end{bmatrix} = \begin{bmatrix} Y_{ic}^B \\ Y_{cc}^B \end{bmatrix} \left(Y_{cc}^A + Y_{cc}^B\right)^{-1} \delta_{c,free}^A$$

Remarks

1. These concepts are relatively well-known in acoustics (“blocked force and free velocities”) but not very common in structures.

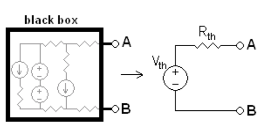
2. Theoretical relation between blocked force and free interface displacement:

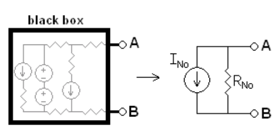
$$\delta_{c,free}^A = -Y_{cc}^A f_{c,blocked}^A \qquad \text{and} \qquad f_{c,blocked}^A = -\left(Z_{cc}^A - Z_{ci}^A Z_{ii}^{A^{-1}} Z_{ic}^A\right) \delta_{c,free}^A$$

The blocked force is the force needed on the interface to counteract the free interface displacements

1. These approaches are conceptually comparable to the Norton and Thevenin equivalent circuits in electricity

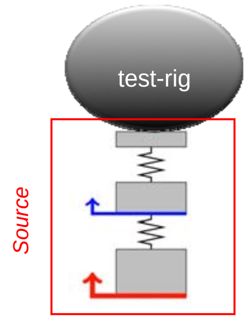
[pictures from wikipedia.org]





Remarks

4. In practice realizing perfectly fixed or free interface conditions can be difficult. Often a support structure is attached to the source.



- If FRFs of source and test-rig are known then the blocked force can be deduced from

$$\begin{bmatrix} u_i^B \\ u_c^B \end{bmatrix} = -\begin{bmatrix} Y_{ic}^B \\ Y_{cc}^B \end{bmatrix} \left(Y_{cc}^A + Y_{cc}^B\right)^{-1} Y_{cc}^A f_{c,blocked}^A$$

- If only the FRF of the assembly is known, then the blocked force can be deduced from the assembled dynamic equivalent equilibrium

$$\begin{bmatrix} Y_{cc}^{A+B} & Y_{ci}^{A+B} \\ Y_{ic}^{A+B} & Y_{ii}^{A+B} \end{bmatrix} \begin{bmatrix} -f_{c,blocked}^A \\ 0 \end{bmatrix} = \begin{bmatrix} u_c^B \\ u_i^B \end{bmatrix}$$

Requires measuring enough dofs in B and/or on the interface (*in situ* method [4])

References and bibliography *(non exhaustive!)*

- 1 D. de Klerk. *Dynamic Response Characterization of Complex Systems through Operational Identification and Dynamic Substructuring: An application to gear noise propagation in the automotive industry.* PhD thesis, Delft University of Technology, Delft, The Netherlands, March 2009.
- 2 G. van Schothorst, A. Boogaard, T. van der Poel, and D. Rixen. Analysis of ground vibration transmission in high precision equipment by frequency based substructuring. In P. S. et al., editor, *International Conference on Noise and Vibration Engineering, ISMA*, number 915, KUL, Leuven, Belgium, 17-19 September 2012.
- 3 D. J. Rixen, A. Boogaard, M. V. van der Seijs, G. van Schothorst, and T. van der Poel. Source description in vibration transmission between substructures: blocked forces and free velocities. *Journal of Sound and vibration*, (submitted), 2014.
- 4 A. Moorhouse, A. Elliott, T. Evans, In situ measurement of the blocked force of structure-borne sound sources, Journal of Sound and Vibration 325 (4–5) (2009) 679 – 685. doi:http://dx.doi.org/10.1016/j.jsv.2009.04.035. URL `http://www.sciencedirect.com/science/article/pii/S0022460X09003794`